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The association of widely used electromagnetic waves exposure and pregnancy and birth outcomes in Yazd women: a cohort study

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Abstract

Background The present study investigated the association between exposure to electromagnetic waves from widely used devices and pregnancy and birth outcomes among women in Yazd City.

Methods This study was conducted on a total of 1,666 participants enrolled in the Yazd Mother and Child Cohort Center between 2015 and 2019. Cell phones, cordless phones, and Wi-Fi instruments were considered electromagnetic wave sources. Pregnancy and birth outcomes examined in this study include miscarriage, preterm labor, abnormal birth weight, and deviations in newborn height and head circumference. SPSS version 24 and R-studio version 4.3.1 software were used for statistical analysis.

Results The current study revealed that 41 (2.5%) mothers had miscarriage and 174 (10.4%) mothers experienced preterm labor. Furthermore, 181 (10.9%) infants with abnormal birth weights, 117 (7%) infants with abnormal height, and 124 (7.4%) infants with abnormal head circumference were observed in this study. Individuals with longer cell phones call duration during pregnancy had higher risk of miscarriage ($p < 0.001$, RR (95% CI), 1.0061(1.003–1.0093)), abnormal birth weight ($p = 0.002$, RR (95% CI), 1.0012 (1.0004–1.002)) and height ($p = 0.003$, RR (95% CI), 1.0014 (1.0004–1.0023)) in comparison with those with lower cell phone call duration in this period.

Conclusion The findings of the study revealed that an increase in exposure to cell phones during pregnancy can increase the risk of pregnancy and birth outcomes, namely miscarriage, abnormal weight and height of the infant. Furthermore, cordless phone conversations could increase the risk of abnormal weight in newborns.

Keywords Miscarriage, Abortion, Radio waves, Birth weight, Pregnancy outcome

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Introduction

Non-ionizing radiation is a part of the spectrum of electromagnetic waves with a wavelength of 300 nm to more than 1 m, in which there is not enough energy to cause ionization in atoms. These include extremely low-frequency rays (ELF), radio waves, microwaves, infrared, visible light, and some ultraviolet rays [1]. As an inseparable part of the modern lifestyle, cell phones communicate by broadcasting and transmitting radio waves ranging from 10 to 1000 m through fixed antennas called base stations (BTS) [2]. Cell phones emit waves in the radiofrequency region of the electromagnetic spectrum. Second-, third-, and fourth-generation cell phones (2G, 3G, 4G) emit radiofrequency in the frequency range of 0.7–2.7 GHz. Fifth-generation (5G) cell phones are anticipated to use a frequency spectrum of up to 80 GHz [3].

Since the reports indicate an estimate of about 9.6 billion cell phone subscriptions worldwide, the growing use of these tools requires investigation, research, and monitoring of their effects on the public [2]. The global number of smartphone users predicted to continuously increase between 2024 and 2029 by 1.5 billion users (+30.6%), leading to a new peak in 2029 [4].

With the growing progress of technology, humans have been exposed to electromagnetic waves in various fields of industry, agriculture, security and military, telecommunications, medicine and so forth. These rays include very low-frequency rays, radio waves, microwaves, infrared, visible light, and a part of ultraviolet rays [5].

Radiofrequency electromagnetic including cellphone signals, are invisible form of energy that can alter biological responses. Heat generation is also a well-known biological effect of radiofrequency electromagnetic fields (RF-EMF) on radiofrequency (RF) signals exceeding 100 kHz. Exposure to RF signals at a specific absorption rate (SAR) of >4 W/kg induced thermal effects has led to the establishment of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines (1998) [6]. Cell phones, as an integral part of the world of communication, communicate through a network of fixed antennas. Therefore, cell phones, cordless phones and Wi-Fi devices are common tools used daily [7]. The International Agency for Research on Cancer (IARC) convened an international expert working group as part of its Monographs Program to evaluate human carcinogenic risks. They classified radiofrequency electromagnetic fields emitted by cell phones – as "possibly carcinogenic to humans" [8]. As billions of people use cell phones globally, a small increase in the incidence of adverse effects on health could have major public health implications on a long-term basis. Besides, the number of cell phone calls per day, the length of each call, and the amount of time people use cell phones are important factors leading to health-related risks [9].

It is evident that certain groups in society, such as pregnant women, children, individuals with chronic conditions and the elderly are at greater risk of exposure to health-threatening factors. The health of the pregnant woman is directly related to the health of the fetus and its offspring. Consequently, this study aims determination of the association between exposure to electromagnetic radiation from widely used sources and the pregnancy and birth outcomes of in the population of women living in Yazd from 2015 to 2019.

Methods

Data collection

Data related to exposure to electromagnetic waves were obtained from the database of Yazd Mother and Child Cohort Center (Shahid Sadoughi University of Medical Sciences). The data used in this study includes electromagnetic waves emitted from widely used sources. The data related to mobile and cordless phones, such as the number of calls and the average duration of the conversation, have also been investigated. The study surveyed the presence or absence of wireless internet routers at home and work, the frequency of being turned on during the day and night, and the duration of their use. Moreover, in order to conduct further examination, the location of these devices such as the location of cell phones and cordless phones during conversation and the location of Wi-Fi routers, was considered in the study. Other sources, such as electrical appliances, solar ultraviolet rays, solarium, and others, have been omitted from the study due to the lack of information. The data related to the amount of exposure was self-reported by the mothers.

Mother's weight and age, occupation and education level, birth order, smoking history of father, mother, or both, alcohol use, history of certain diseases in the family, economic status, birth records, social status, and lifestyle variables were also gathered during data collection. In this study, the cohort's data (2015-2019) related to 2137 pregnant women and the state of childbirth and their children, as well as their exposure to widely used sources that emitted electromagnetic waves during pregnancy has been examined. It should be mentioned that 417 samples were excluded from the study due to insufficient information (Fig. 1).

1. Demographic variables included occupation, income, level of education, and age.
2. Main variables that include:

a) Five pregnancy and childbirth outcomes, i.e., miscarriage, preterm labor, abnormal birth weight, abnormal infant height and abnormal head circumference.

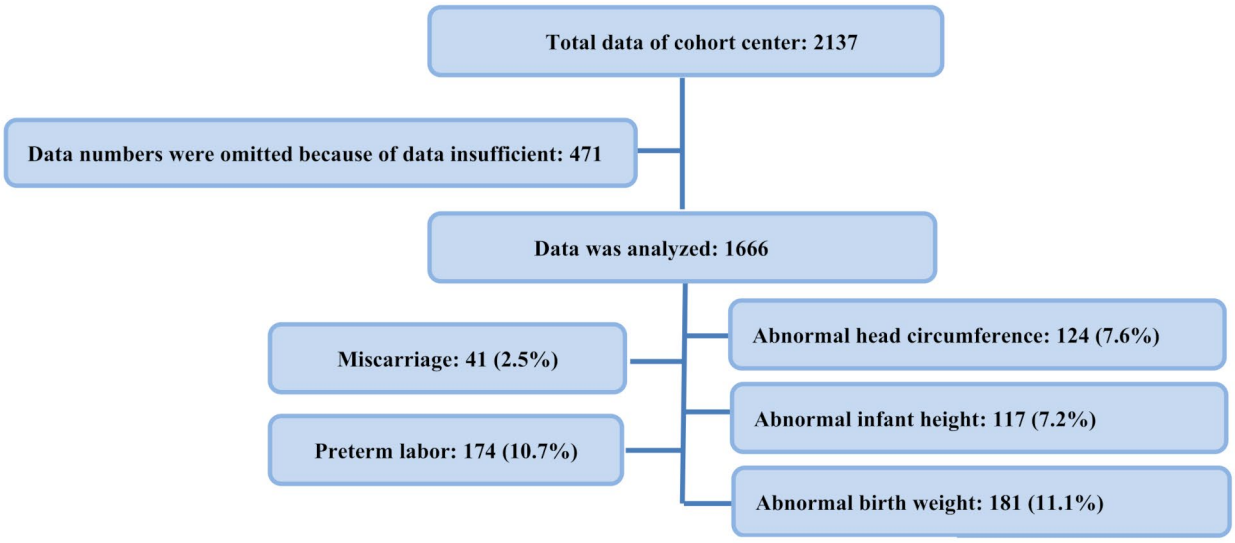

Fig. 1 The steps of data cleaning in the present study

b) Six main exposure levels, including the duration of a cell phone conversation during pregnancy, the number of cell phone calls per day, the duration the cordless phone conversations as number per day, the number of cordless phone calls, the duration of exposure to Wi-Fi radio waves, and the number of text messages sent by cell phones during pregnancy.

3. Confounding variables include the history of diseases, history of exposure to X-rays (X-ray and CT-scan), MRI history, and the location of the resident's house in the territory of power transmission lines and cell phone base transceiver station (BTS) antennas.

Statistical analysis

Initially, data were entered into SPSS version 24 software. Exposures related to the amount of cell and cordless phone conversations and number calls were recorded separately based on the duration of pregnancy. Subsequently, the exposure of a person to Wi-Fi waves at home and work was calculated based on the available data. The number of text messages sent by the person was also collected during the whole pregnancy period.

Furthermore, variables such as cancer, asthma, diabetes, high blood pressure, and epilepsy were considered as a history of diseases.

In order to do the final analysis of the data, the R-studio software version 4.3.1 was used. This software examined the effect of exposure to electromagnetic waves on pregnancy and birth outcomes by fitting the exact log-binomial regression model. The models used in this study include the log-binomial model, placed in the category of generalized linear models, and its form is as follows:

$$\ln(\mathrm{p}) = \beta\_0 + \beta\_1 \mathrm{x}\_1 + \ldots + \beta\_\mathrm{k}\, x\_\mathrm{k} \qquad (1)$$

Where x represents the predictor variable, β denotes the regression coefficients, and p refers to the risk of the outcome [10]. According to the specified statistical model, three models were applied to examine the association between exposure to electromagnetic waves and outcomes.

Model 1: Examining the association between the pregnancy and childbirth outcome variables and cell phone talk duration, cordless phone conversation duration, duration of exposure to Wi-Fi, and a number of text messages separately using **univariate** analysis.

Model 2: Investigating the association between the pregnancy and childbirth outcome variables and all sources of electromagnetic waves (duration of cell phone conversation, duration of cordless phone conversation, duration of exposure to Wi-Fi, and number of text messages sent), simultaneously using multivariable analysis.

Model 3: Examining the association between the pregnancy and childbirth outcome variables and all sources of electromagnetic waves (duration of cell phone conversation, duration of cordless phone conversation, duration of exposure to Wi-Fi, and number of text messages sent) simultaneously while **adjusting the effect of confounding variables** (e.g., age, income, level of education, occupation, disease history, history of X-ray, CT-Scan and MRI, the presence of power transmission lines around the house, and the presence of cell phone BTS antennas around the house) simultaneously using multivariable analysis.

The determinants of miscarriage, preterm labor, and abnormal weight, height, and head circumferences in

infants were investigated separately using a log-binomial regression model.

Results

Frequency of miscarriage and preterm labor, abnormal birth weight, height, and head circumference were reported concerning demographic and confounding variables. It was observed that the relationship between education level and miscarriage was significant ($P < 0.001$). In addition, the association the mother's age with miscarriage ($p = 0.02$) and preterm labor ($p = 0.01$) was significant (Table 1).

Miscarriage

The current study revealed that 41 (2.5%) mothers had miscarriage. The ratios of cases to covariates number are 10.25 and 2.92 in models 2 and 3 since there are 4 and 14 predictor variables in mentioned models, respectively.

The results of the models demonstrated that the duration of cell phone conversations significantly affected miscarriage in all models ($p < 0.001$). Additionally, the duration of cordless phone calls had a significant effect on miscarriage in model 2 ($p = 0.003$) (Table 2).

As shown in Fig. 2, the results of fitting model 1 indicated that for every 6-hour increase in the duration of talking on a cell phone, the risk of miscarriage increases by 1.5%. For every 24-hour increase, the risk of miscarriage increases by 6.1%. Latter findings reflect the

Table 1 Demographic and confounding variables of the studied women

Variable		frequency	outcome				
			With Miscarriage ($n = 41$)	with Preterm Labor ($n = 174$)	Infants with Abnormal birth weight ($n = 181$)	Infants with Abnormal height ($n = 117$)	Infants with Abnormal head circumference ($n = 124$)
			Frequency(%)	Frequency(%)	Frequency(%)	Frequency(%)	Frequency(%)
Age (Year)	< 20	111	5 (4.5%)	15 (14.2%)	13 (12.3%)	10 (9.4%)	6 (5.7%)
	20–35	1278	24 (1.9%)	119 (9.5%)	140 (11.2%)	87 (6.9%)	104 (8.3%)
	> 35	277	12 (4.3%)	40 (15.1%)	28 (10.6%)	20 (7.5%)	14 (5.3%)
	p-value		**0.02**	**0.01**	0.89	0.6	0.17
Income	Low	1461	41 (2.8%)	160 (11.3%)	163 (11.5%)	104 (7.3%)	114 (8%)
	Average	174	0	12 (6.9%)	15 (8.6%)	12 (6.9%)	9 (5.2%)
	High	31	0	2 (6.5%)	3 (9.7%)	1 (3.2%)	1 (3.2%)
	p-value		0.052	0.15	0.51	0.67	0.26
Education	< Diploma	847	41 (4.8%)	99 (12.3%)	93 (11.5%)	70 (8.7%)	62 (7.7%)
	Associate and Bachelor	700	0	67 (9.6%)	78 (11.1%)	39 (5.6%)	56 (8%)
	Master and Higher	119	0	8 (6.7%)	10 (8.4%)	8 (6.7%)	6 (5%)
	p-value		***P < 0.001***	0.08	0.59	0.06	0.53
Occupation	Self-employment	132	2 (1.5%)	15 (11.5%)	18 (13.8%)	12 (9.2%)	10 (7.7%)
	Employee	191	4 (2.1%)	22 (11.8%)	18 (9.6%)	17 (9.1%)	17 (9.1%)
	House-wife	1280	35 (2.7%)	133 (10.7%)	143 (11.5%)	86 (6.9%)	90 (7.2%)
	Without job	63	0	4 (6.3%)	2 (3.2%)	2 (3.2%)	7 (11.1%)
	p-value		0.46	0.66	0.13	0.32	0.58
With Disease history		144	2 (1.4%)	15 (10.6%)	16 (11.3%)	9 (6.3%)	10 (7%)
		p-value	0.38	0.9	0.95	0.67	0.78
With X-ray history		67	0	9 (13.4%)	7 (10.4%)	6 (9%)	7 (10.4%)
		p-value	0.18	0.46	0.85	0.57	0.37
With CT-Scan history		9	0	1 (11.1%)	0	0	0
		p-value	0.63	0.96	0.28	0.4	0.38
With MRI history		7	0	2 (28.6%)	1 (14.3%)	0	0
		p-value	0.9	0.29	0.9	0.7	0.71
presence of power transmission lines[1]		23	1 (4.3%)	2 (9.1%)	0	0	0
		p-value	0.55	0.8	0.09	0.18	0.17
presence of cell phone, BTS antennas[2]		22	0	3 (13.6%)	2 (9.1%)	2 (9.1%)	3 (13.6%)
		p-value	0.45	0.65	0.75	0.73	0.28

1. Presence of power transmission lines in the privacy of the home (distance below 100 m)

2. Presence of cell phone BTS antennas in the privacy of the home (distance below 100 m)

Table 2 The association between common electromagnetic exposure sources and the miscarriage outcome in the present study

	Model No.1 ($n=1666$)			Model No.2 ($n=1666$)			Model No.3 ($n=1666$)		
Variables	**RR**	**CI**	**p**	**RR**	**CI**	**p**	**RR**	**CI**	**p**
Duration of cell phone conversation (hour)	1.00252	1.0018–1.0031	***P*<*0.001***	1.0042	1.0038–1.0046	***P*<*0.001***	1.0061	1.003–1.0093	***P*<*0.001***
Duration of cordless phone conversation (hour)	1.0019	0.9982–1.0056	**0.2**	0.996	0.9933–0.9986	***0.003***	0.999	0.99–1.008	**0.83**
Duration of exposure to Wi-Fi (hour)	0.9988	0.9956–1.002	**0.47**	0.9989	0.9959–1.002	**0.5**	1.0018	0.9992–1.0043	**0.16**
Number of sent SMS	1.000258	0.9993–1.0011	**0.56**	1.0003	0.9995–1.001	**0.4**	1.0002	0.9991–1.0012	**0.67**

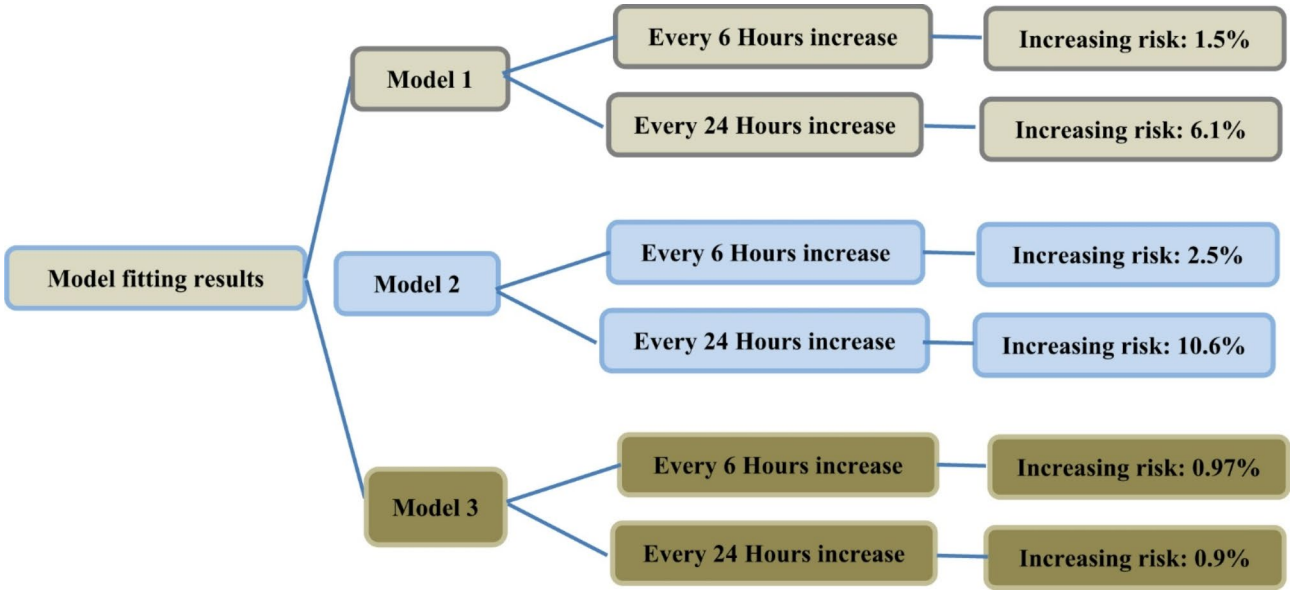

Fig. 2 The relative risk increase related to miscarriage outcomes via cell phone conversation

comparison in risk of miscarriage between individuals with higher cell phone call duration and those with lower call duration.

Moreover, the results of fitting model 2 revealed that for every 6 h of increase in the duration of the cell phone conversation, the risk of miscarriage increases by 2.5% and for every 24 h of increase in the duration of the conversation on the cell phone, the risk of miscarriage increases by 10.6%. Furthermore, the results of the fitting model 3, for every 6 h of increase in the duration of the cordless phone conversation, the risk of miscarriage increases by 0.97% and for every 24 h of increase in the duration of the conversation on the cordless phone, the risk of miscarriage increases by 0.90%. These reflect the comparison in risk of miscarriage between individuals with higher cordless call duration and those with lower call duration.

The results of fitting model 3, in which the effect of demographic variables, confounding variables, and other exposures have been adjusted, indicated that by every 6-hour increase in the duration of the cell phone conversation, the risk of miscarriage increases by 3.7%. For every 24 h, an increase in the duration of conversation with a cell phone will increase the risk of miscarriage by 16% (Fig. 2).

Preterm labor

In this study, 174 mothers (10.4%) experienced preterm labor. The ratios of cases to covariates number are 43.5 and 12.42 in models 2 and 3 since there are 4 and 14 predictor variables in mentioned models, respectively.

The results from the model fitting showed that none of the commonly identified sources of electromagnetic sources were significantly associated with preterm labor (Table 3).

Abnormal birth weight

In this study, 181 (10.9%) abnormal birth weights were observed. The ratios of cases to covariates number are 45.25 and 12.92 in model 2 and 3 since there are 4 and 14 predictor variables in mentioned models, respectively. The duration of the cell phone conversation significantly affected the abnormal birth weight in model 1 ($p=0.02$), model 2 and model 3 ($p=0.002$). Furthermore,

Table 3 The association of common electromagnetic exposure sources and the preterm labor outcome

	Model No.1 ($n=1666$)			Model No.2 ($n=1666$)			Model No.3 ($n=1666$)		
Variable s	**RR**	**CI**	***p***	**RR**	**CI**	***p***	**RR**	**CI**	***p***
Duration of cell phone conversation (hour)	1.00013	0.9993–1.0009	**0.72**	1.0006	0.9994–1.0018	**0.3**	1.0004	0.9992–1.0016	**0.4**
Duration of cordless phone conversation (hour)	0.9979	0.9953–1.0004	**0.1**	0.9979	0.9955–1.0003	**0.09**	0.9982	0.9958–1.0006	**0.1**
Duration of exposure to Wi-Fi (hour)	0.9997	0.9993–1.0002	**0.36**	0.9998	0.9994–1.0002	**0.51**	0.9999	0.9994–1.0003	**0.71**
Number of sent SMS	0.9998682	0.9996 – 1.0001	**0.33**	0.9998	0.9996–1.0001	**0.3**	0.9998	0.9996–1.0001	**0.4**

Table 4 The association of common electromagnetic exposure sources and abnormal birth weight in the present study

	Model No.1 ($n=1666$)			Model No.2 ($n=1666$)			Model No.3 ($n=1666$)		
Variable s	**RR**	**CI**	***p***	**RR**	**CI**	***p***	**RR**	**CI**	***p***
Duration of cell phone conversation (hour)	1.0003	1–1.0007	**0.02**	1.0012	1.0004–1.002	**0.002**	1.0012	1.0004–1.002	**0.002**
Duration of cordless phone conversation (hour)	0.9992	0.9974–1.0011	**0.44**	0.9981	0.9965– 0.9997	**0.02**	0.9983	0.9966–0.9999	**0.04**
Duration of exposure to Wi-Fi (hour)	1.0001	0.9998–1.0004	**0.46**	1.00009	0.9997– 1.0003	**0.5**	1.00017	0.9998–1.0003	**0.3**
Number of sent SMS	1.000095	0.9999–1.0002	**0.14**	1.00008	0.9999– 1.0002	**0.27**	1.000097	0.9999–1.0002	**0.16**

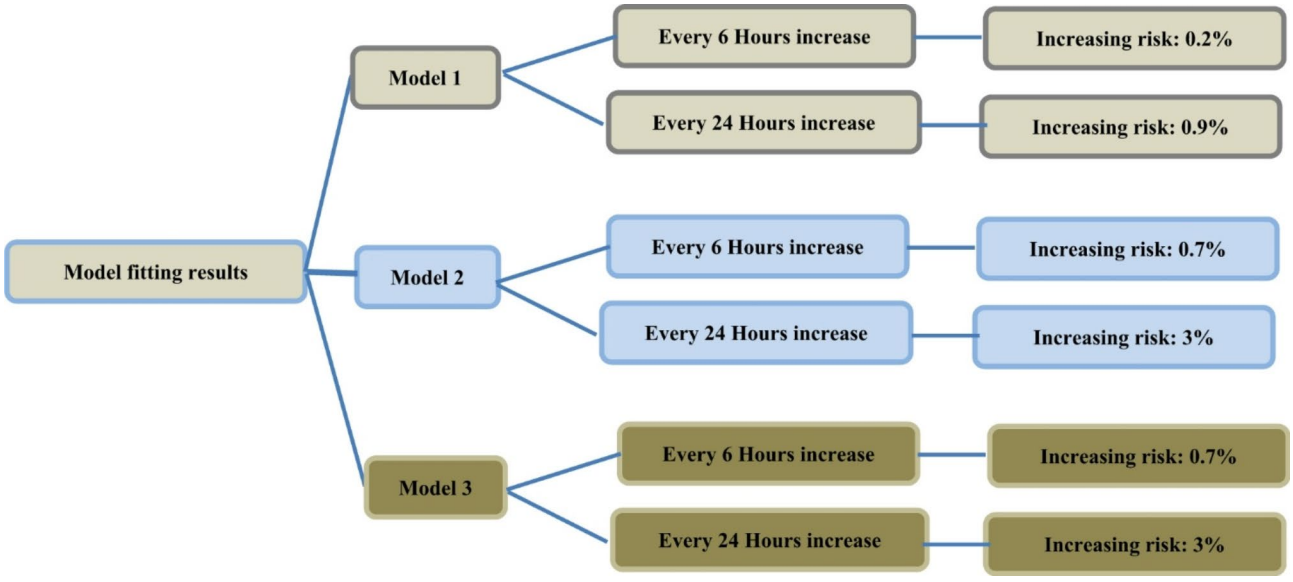

Fig. 3 Increasing risk of abnormal infant weight by increasing in cell phone conversation

the duration of cordless phone conversations was significantly associated with abnormal birth weight in model 2 ($p=0.02$) and model 3 ($p=0.04$) (Table 4).

So, increasing risks related to abnormal birth weight are presented in Fig. 3. As shown, the risk of abnormal birth weight increased by 0.2% for every six hours of increased cell phone conversation. Moreover, for every 24 h of increased cell phone conversation, the risk of abnormal birth weight increased by 0.9% (Model 1).

In addition, in the fitting of models 2 and 3, the risk of abnormal birth weight increased by 0.7% for every 6-hour increase in cell phone talk and by 3% for every 24-hour in cell phone conversation (Fig. 3).

Furthermore, for every 6-hour increase in the cordless phone conversation in models 2 and 3, the risk of abnormal birth weight increased by 0.98%. Also, for every 24-hour of increased cordless phone conversation, the risk of abnormal birth weight increased by 0.95% in model 2 and 0.96% in model 3, respectively.

Abnormal height

In this study, it was observed that 117 (7%) of infants had abnormal height. The ratios of cases to covariates number are 29.25 and 8.35 in model 2 and 3 since there are 4 and 14 predictor variables in mentioned models, respectively.

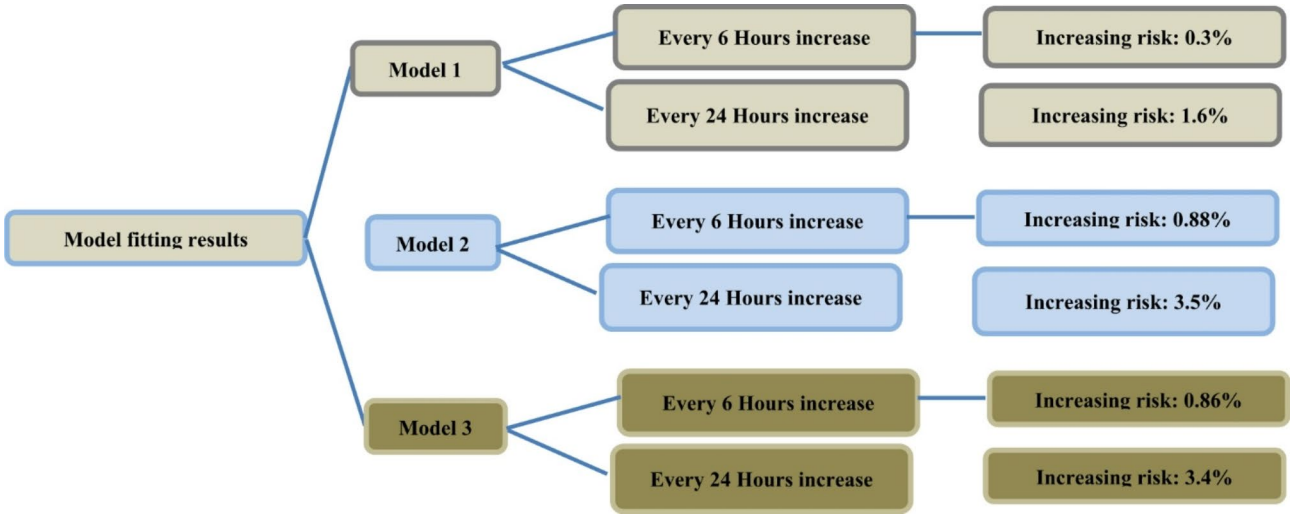

Fig. 4 Increasing risk of abnormal infant height by increasing amount of cell phone conversation

Table 5 The association of common electromagnetic exposure sources and abnormal infant height in the present study

	Model No.1 ($n=1666$)			Model No.2 ($n=1666$)			Model No.3 ($n=1666$)		
Variable s	**RR**	**CI**	***p***	**RR**	**CI**	***p***	**RR**	**CI**	***p***
Duration of cell phone conversation (hour)	1.00066	1.0006–1.0007	***P*** **<** ***0.001***	1.0014	1.0004–1.0024	**0.003**	1.0014	1.0004–1.0023	**0.003**
Duration of cordless phone conversation (hour)	1.00049	0.9996–1.0013	**0.25**	0.9985	0.9967–1.0003	**0.1**	0.9989	0.9971–1.0007	**0.26**
Duration of exposure to Wi-Fi (hour)	0.9999	0.9994–1.0004	**0.74**	0.9999	0.9994–1.0004	**0.85**	0.9999	0.9994–1.0004	**0.93**
Number of sent SMS	0.9998	0.9994 – 1.0001	**0.29**	0.9997	0.9994–1.0001	**0.21**	0.9997	0.9994–1.0001	**0.23**

Table 6 The association of common electromagnetic exposure sources and abnormal infant's head circumferences in the present study

	Model No.1 ($n=1666$)			Model No.2 ($n=1666$)			Model No.3 ($n=1666$)		
Variable s	**RR**	**CI**	***p***	**RR**	**CI**	***p***	**RR**	**CI**	***p***
Duration of cell phone conversation (hour)	1.0003	0.9997–1.0009	**0.23**	1.0007	0.9996–1.0018	**0.16**	1.0007	0.9996–1.0018	**0.16**
Duration of cordless phone conversation (hour)	0.9998	0.9981–1.0014	**0.82**	0.999	0.9971–1.001	**0.36**	0.9993	0.9974–1.0013	**0.53**
Duration of exposure to Wi-Fi (hour)	1.00008	0.9996–1.0004	**0.68**	1.0001	0.9997–1.0005	**0.56**	1.00018	0.9997–1.0006	**0.4**
Number of sent SMS	0.9998	0.9995 – 1.0001	**0.4**	0.9998	0.9995–1.0001	**0.34**	0.9998	0.9995–1.0001	**0.35**

As shown, the duration of the cell phone conversation had a significant relationship with the abnormal height of the newborn in model 1 ($p<0.001$), model 2 and model 3 ($p=0.003$).

Figure 4 depicts the increasing risk related to abnormal infant height. According to Fig. 4, every 6-hour increase in the length of cell phone conversation could increase the risk of infant's abnormal height by 0.3%. Moreover, for every 24-hour increase in the length of cell phone conversation, the risk of this outcome increased by 1.6%.

In model 2 fitting data, for every 6-hour increase in the length of cell phone conversations, the risk of the abnormal height of the infant increases by 0.88%. For every 24-hour increase in the duration of cell phone conversation, the risk of this outcome increases by 3.5%.

The results of fitting model 3 also indicated that the risk of abnormal infant height increased by 0.86% for every six hours of increased cell phone call duration and by 3.4% for every 24-hour increase (Table 5).

Abnormal head circumference

In this study, it was observed that 124 (7.4%) of infants had abnormal head circumference. The ratios of cases to covariates number are 31 and 8.85 in model 2 and 3 since there are 4 and 14 predictor variables in mentioned models, respectively. As shown in Table 6, common

electromagnetic waves have no significant relationship with abnormal head circumference of newborns.

Discussion

The present study aimed to investigate and determine the relationship between electromagnetic waves emitted from commonly used sources (cell phones, cordless phones, and Wi-Fi) and pregnancy and birth outcomes in women living in Yazd City from 2015 to 2019 (Cohort Study). This study revealed that exposure levels significantly influence the frequency of miscarriage and preterm labor. Notably, the duration of crude cell phone conversations during pregnancy impacts on the risk of miscarriage. The findings of this study are based on the significant relationship found between the crude and adjusted duration of cell phone conversations with the risk of miscarriage. As mentioned, this relationship was analyzed using three models. In the first model, the significant effect of the amount of exposure based on the duration of conversation with a cell phone was evident in the outcome of miscarriage. In the second model, the amount of exposure was analyzed based on cell phone conversations adjusted by the number of mobile and cordless calls, as well as cordless phone conversations and the amount of exposure to Wi-Fi devices and the number of text messages, indicating a positive relationship between these variables. In the third model, the variables such as age, education level, income, disease history, mother's occupation, and exposure to diagnostic radiography and MRI, being within the limits of power transmission lines, cell phone BTS antennas were also included in the analysis. Finally, the findings showed that the relationship between the number of cell phone and cordless phone conversations and the rate of miscarriage was significant. In 2022, Musaibi et al., estimated that the duration of the duration of cell phone calls and mobile internet affect the miscarriage rate. They demonstrated that after accounting for the average internet use per hour and while holding other variables constant, the risk of miscarriage increased. Additionally, for each hour of cell phone conversation during pregnancy, the risk of miscarriage increased; however, this relationship was not statistically significant, similar to the present study's results. Also, they indicated that turning off the cell phone at night reduced the risk of miscarriage, but this relationship was not statistically significant [11]. Overall, neither of the two results confirmed that cell phone conversation could affect the risk of miscarriage.

In another study conducted by Shi Luo (2017), the results showed an effective relationship between the incidence of miscarriage and the number of cell phone conversations, which aligns with the results of the present study. The effects of smoking, job, income, and education, as well as the amount of sleep and watching TV, and the possible effects of ionizing radiation were ignored in the analysis. Finally, the risk value was obtained [12].

Mahmoodabadi (2015) found that the cell phone conversation length significantly affected on the risk of miscarriage [13], which is in accordance with the present study's results.

In the present study, no significant relationship was found between preterm labor and the amount and source of exposure to electromagnetic waves. None of the variables of the duration and number of conversations made with cell phones and cordless phones, as well as the amount of exposure to Wi-Fi, had a significant effect on the risk of preterm labor. The present results do not follow the study conducted by Esmaeelzade et al. (2019), which found a significant relationship between being within the limits of power transmission lines and increasing preterm labor. This difference could be due to the fact that in that study, there were cases that lived less than 600 m from power transmission lines, while in the current study, the confounding effect of this variable has not been investigated. As a result, it was not significant [14]. Sadeghi et al. (2017) investigated the effect of power transmission lines on pregnancy and birth outcomes. The effect of variables such as age, occupation, and level of education were considered. They discovered that living within the limits of power transmission lines and preterm labor have a significant relationship [15]. The difference in the number and type of variables can explain the reason behind this difference. Moreover, the number of samples (288 cases) can influence the results.

According to the results of the present study, there is a significant relationship between the weight of the infant and cell and cordless phone conversation duration. Although cell phone conversation has a crude and adjusted effect on the outcome of abnormal weight, the cordless phone had a significant relation in an adjusted mode. Boylia (2020) also showed in a similar study that an increase in exposure of pregnant women to cell phones led to an abnormal weight in their children, so their results were similar to the present study. The risk value of the confounding model was less than 0.05 [16].

In another study, Mortazavi et al. investigated the relationship between the infant's weight and the mother's exposure to cell and cordless phones (2013). Their results showed that the effects of diagnostic X-rays and cell and cordless phones conversation had no significant effect on the infant's weight [17], while the results of the present study contrast with the mentioned findings. Nevertheless, this difference may be due to the difference in the used statistical models and the consideration of ionizing radiation as a primary variable that was not calculated in the analysis.

Yanfeng Ren's study (2019), investigating the effect of electromagnetic waves on pregnancy outcomes in 128

pregnant women, concluded that these waves can effectively affect the infant's weight with a risk value of less than 0.05 [18]. In 2015, Wahlberg Bist observed that an increase in the use of cell phones can affect the infant's weight [19].

Also, the results showed that using cell phones had a significant effect on the occurrence of abnormal height in newborns. Mehram and Qazavi (2013) conducted a study on 222 pregnant women exposed to low-frequency electromagnetic waves from power transmission lines. They reported that there is an effective relationship between being within the limits of power transmission lines and the strength and height of the infant [20], which is not in line with Mehram and Qazavi's study. The difference in the variables could cause this difference. In the above study, the effect of cell and cordless phone radiations was not considered, and only the effect of being within the limits of very low-frequency waves and the moderating effect of demographic variables were investigated.

The outcome of the abnormal head circumference of the newborn was also investigated in the present study. The results showed no significant relation between the electromagnetic waves emitted by cell phones, cordless phones, and Wi-Fi and the result of abnormal head circumference in newborns. Using data from a cohort of 21,714 cases, a similar study by Turner et al. (2022) revealed that income levels can influence an infant's head circumference [16]. The findings of the study by Yang et al. (2019) showed that power transmission lines can affect the infant's head circumference. However, in this study, a significant relationship was obtained only in the group of female infants [18].

Strengths and weakness of the study

This study's strengths include using three model definitions, both with and without confounding variables, and the comparative analysis of these models. Additionally, the study benefits from a sufficiently large sample size. Although self-report data may introduce recall bias, this is mitigated because exposure information in the current cohort study was collected during pregnancy. Recording the exposure information from mothers monthly throughout their pregnancy could minimize the risk of selection bias. The primary limitation of this study is the significant number of mothers who withdrew from the cohort due to incomplete information, which could be considered a weakness of the study. Results show that the association between the outcome variable and exposures getting stronger with an increasing number of covariates in the model. This could indicate that the covariates are capturing important underlying relationships rather than negative confounding.

Conclusion

The relationship between common electromagnetic wave exposure (cell phones, cordless phones, Wi-Fi, and others) and pregnancy and birth outcomes was investigated. According to the results of the statistical analysis of this research, it could be concluded that some outcomes, such as miscarriage, abnormal weight, and height of the infant, could be affected by the crude cell phone conversation duration. Furthermore, adjusting the effect of cell phone conversation along with the effect of other exposures, demographic and confounding variables affect miscarriage and abnormal weight and height of the infant. The effect of cordless phone use on the risk of abnormal weight of the infant was observed only in adjusted models. No significant relationship was found between the crude cordless phone conversation and other outcomes of pregnancy and birth. Further research is needed to determine the specific health effects of electromagnetic waves. However, based on the results of the present study, it is recommended that public education be promoted to enhance self-health awareness, particularly during pregnancy, as advised by healthcare providers.

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Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Fahimeh Teimouri and Mohammad Hassan Ehrampoush; data collection: Mohammad Razavi Moghaddam; analysis and interpretation of results: Reyhane Sefidkar, Mohammad Hosein Zare and Fahimeh Nakhostin; draft manuscript preparation: Mohammad Razavi Moghaddam and Fahimeh Teimouri. All authors reviewed the results and approved the final version of the manuscript.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Conflict of interest

The authors declared that there is no conflict of interest in the present study.

Ethical approval and consent to participate

The birth cohort study was conducted according to the guidelines laid down in the Declaration of Helsinki and informed consent was obtained from participants or legally authorized representatives of illiterate participants. Each participant was provided with detailed information regarding the study's purpose, procedures, potential risks, and benefits. Consent was obtained voluntarily, ensuring that participants understood their right to withdraw from the study at any time without any consequences. The study was approved by

the relevant ethics committee (IR.SSU.SPH.REC.1400.087), ensuring adherence to ethical standards in research.

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